Institute for Nuclear and Particle Astrophysics

R.G. Stokstad

Introduction

The areas of research at the Institute (INPA) are broad and have a strong interdisciplinary flavor, yet a common purpose connects them - to use the science and the technologies of nuclear physics and particle physics to address fundamental questions bearing on the nature of the universe: past, present, and future. Specific research topics include solar neutrinos, high energy neutrinos, detection of nearby and distant supernovae, weak interactions in atomic and nuclear processes, the cosmic microwave background radiation, direct detection of dark matter, cosmic ray chronometers, the theory of pulsars and neutron stars, and geoastrophysics. Research and education are combined not only through the participation of students and postdoctoral researchers, but also at the high school level through summer programs for teachers and a major project, the Hands-On Universe, that brings on-line astronomical images to the classroom.

INPA is sponsored by the Nuclear Science Division and the Physics Division at LBNL. While participants in INPA are predominantly from these two Divisions, the Physics Department and the Space Sciences Laboratory at UC Berkeley are well represented. Indeed, the Institute benefits from the rich concentration of astrophysics in the greater Bay Area. A wide range of experimental facilities is used by INPA participants; at LBNL (the 88-Inch Cyclotron, Gammasphere, Low-Background Counting Facility, Leuschner Observatory), in North America (Sudbury Neutrino Observatory, the Keck Telescopes, nuclear physics facilities at national laboratories and university laboratories), throughout the world (Chile, Australia, Antarctica), and in space (HST, COBE). There is increasing interest in the study of neutrino properties and their use as probes of very energetic objects in the universe.

This overview naturally focuses on research where Nuclear Science Division-associated researchers are heavily involved. A few highlights from other areas are mentioned, and the overview concludes with a brief description of INPA’s institutional activities.

Neutrinos and Neutrino Astrophysics

The Sudbury Neutrino Observatory (SNO), a 1,000-ton heavy-water Cherenkov detector under construction in a nickel mine in Canada, is nearing completion and will be filled with water in April of 1999. This past year saw a number of significant milestones reached. A very significant for the LBNL members of the SNO collaboration occurred in January 1998 when they installed the last of the

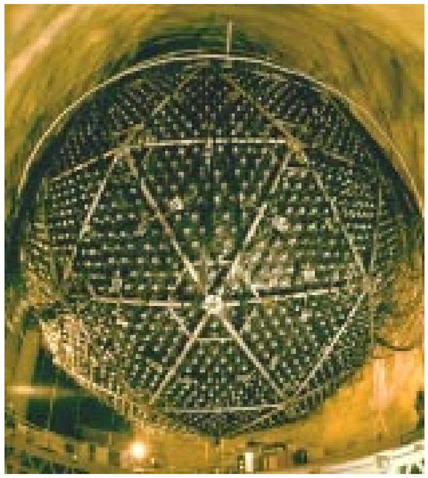

Fig. 1 (left) A wide-angle exterior view of the 17 m. diameter Photo Multiplier Support Structure and a portion of its ~9500 photo multiplier tubes. The cavern housing the SNO detector is located 2020 m. underground.

Fig. 2. (right) A wide-angle interior view (from the bottom of the PSUP, looking upward) showing the Acrylic Vessel, which will containing the heavy water, and the surrounding faces of the p.m. tubes and their reflectors.

~9500 photomultiplier tubes (PMTs) in the geodesic support sphere (or PSUP). The views of the completed detector, from outside and inside, as shown in the wide-angle photographs above, have received wide circulation. Another major milestone, to be passed in April, 1999, will be the filling of the detector with heavy and light water. At that time a detailed evaluation of the performance of the detector, including backgrounds can begin. Attention at LBNL is now focused increasingly on calibration (^{16}N, ^{17}N, and (p,t) sources, activated NaI and LED light sources), neutron detection (^{3}He neutron detectors), data acquisition (graphical interfaces and monitoring) and preparation for data analysis (Monte Carlo simulation and measurement of β and γ backgrounds, simulation of high-energy events). LBNL is also devoting significant effort to building and installing several removable PMT arrays that can be removed from the cavity. These will serve as a long term diagnostic monitor for the PMTs, reflectors, cables and HV connectors.

The same properties of neutrinos that make them a valuable probe of the sun could also make them a unique window on the most energetic objects in the cosmos. A number of INPA participants are members of the AMANDA collaboration, which is constructing a water Cherenkov detector in deep Antarctic ice to observe high energy neutrinos. With 10 strings of PMTs operating AMANDA has now detected up-going muons, the signature of high energy neutrinos. These first events are certainly of atmospheric origin. INPA, with cooperation from NERSC, is heavily involved in the analysis of the large amounts of data generated by the current array of 13 strings and ~400 PMTs. INPA is also making a major contribution in the planning and R&D toward the next generation neutrino observatory. This future detector will have dimensions on the order of a square or cubic kilometer, and therefore have the sensitivity to detect neutrinos from distant point sources, such as Active Galactic Nuclei. The research made possible by drilling holes to great depth in Antarctic Ice goes beyond neutrino physics to include seismology, geology, biology, etc. All these interdisciplinary aspects are the subject of a proposed NSF Science and Technology Center called "Deep Ice."

The properties of neutrinos, in particular, whether they have mass, are of fundamental importance to astrophysics and cosmology, as well as to the standard model of particle physics. SNO is a prime example of a neutrino oscillation experiment. Other major experiments bearing on neutrino mass being actively investigated by INPA members with a view toward participation use reactor neutrinos (KamLAND) or double beta decay (CUORE).

Nuclear Astrophysics

Knowing the half life of unstable (but long-lived) nuclei present in cosmic rays makes it possible to determine the residence time of these nuclei in our galaxy, i.e., they can serve as a cosmic chronometer. In this case, the half lives need to be of the order of 10^6 years. The decay rate of a nucleus in space (where it has no surrounding electrons to capture) can be much longer than when it is housed in an atom or ion on earth. Measurements of very weak β^+ decay branches are therefore necessary. ^{144}Pm and ^{54}Mn and ^{56}Ni are three such cases; the latter nucleus is of particular interest because it has recently been possible to measure the relative abundance of the Mn isotopes in cosmic rays. Recent experiments using Gammasphere at the 88-Inch Cyclotron have placed a lower limit of 2.7 x 10^4 years on the cosmic-ray half-life of ^{56}Ni.

Since there is growing interest in nuclear astrophysics (and other areas of nuclear physics) in measuring cross sections on target nuclei that are off the line of stability, and hence radioactive, a series of thermal neutron capture measurements on the unstable isotopes ^{44}Ti, ^{68}Ge, and ^{148}Gd was initiated using neutrons from Oregon State University reactor. These measurements have now been completed.

Data for Nuclear Astrophysics

Nuclei heavier than lithium can only be made in stars, and in the later, rapid burning and explosive stages of stellar evolution. The prediction of the abundance of these nuclei is a triumph of nuclear astrophysics, and requires an amount of nuclear information on a similarly grand scale. INPA, the Isotopes Project, and UC Santa Cruz have assembled a number of the data-bases used in nucleosynthesis calculations and made them available to the community through our new Nuclear Astrophysics Data Home Page. The type and range of data available through this site has continued to grow as has the number of visitors to the web site.

Weak Interactions and Fundamental Measurements

The standard model of particle physics is the cornerstone for understanding the origin and development of the universe. Many of the key elements or parameters of the standard model are reflected in nuclear properties and measured in precision low-energy nuclear (or even atomic) experiments. It is possible to establish, test, and look for physics beyond the standard model in these nuclear physics experiments. Parity non-conservation, second class currents, time reversal invariance, the conserved vector current theory, double beta decay - these are some of the topics studied in the physics of weak interactions.

Progress continues to be made in a series of experiments involving ^{21}Na (laser trapping, parity non conservation), neutron decay (time reversal invariance and parity violation), ^{14}O (test of the CVC hypothesis) ^{10}C (unitarity of the CKM matrix), ^{8}B (solar neutrino problem), ^{56}Co (time reversal invariance, and Yb (atomic parity non-conservation).

Low Background Counting

The Low Background Counting Facilities used in the study of $\beta\beta$ decay have also been instrumental in a wide variety of experiments and in support activities for other institutions. The other types of work (done at the facilities at Berkeley and at Oroville) include low-activity materials certification, cosmic ray activation, neutron activation analysis, and environmental health and safety activities.

Astrophysics and Cosmology in the Physics Division

We mention here two INPA projects that address the early history and the ultimate fate of the universe and which are based in the Physics Division. The cosmic microwave background radiation observed today reflects the state of the universe about $3x10^5$ years after the Big Bang, at the time radiation and matter decoupled. The next generation of satellites, to follow COBE in the study of anisotropies in the CMBR, are being planned.

The fate of the universe depends on its matter density, which is expressed as a ratio to a critical density at which the expansion rate of the universe slows to zero at infinite time. The supernova cosmology project searches for (and regularly discovers!) type 1A supernovae at very large distances. In essence, the luminosity of a type 1A supernova is a constant or "standard candle," which gives its distance, and the red shift of its host galaxy gives its velocity. Thus, the Hubble diagram can be extended to very large distances (or far back in time). Deviations from a linear dependence of recessional velocity on distance have indicated that Ω_M (the ratio of the mass density of the universe to the critical value) is substantially less than 1 and, equally momentous, that the cosmological constant, Ω_Λ , originally proposed by Einstein and later retracted, is finite. The small value of Ω_M and finite Ω_Λ imply that the universe will expand forever.

Institutional Activities

The purpose of the Institute is to further interdisciplinary work in Nuclear and Particle Astrophysics at LBNL by:

- promoting interaction and communication among its members
- sharing of intellectual, technical, and administrative resources
- planning of new research proposals and development of detector systems
- developing innovative educational outreach programs
- establishing seminar, postdoctoral, and visitor programs
- sponsoring of workshops

The list of active participants has grown to approximately 90, while the number of people receiving e-mail announcements of the weekly Journal Club is ~200. Attendance at the Journal Club is typically 30-40 people. The daily tea has become an established feature of INPA life and attracts usually 15-20 people for conversation and lively argument. The Common Room is heavily used for regularly scheduled group meetings and ad-hoc get-togethers. The list of Journal Club speakers is contained elsewhere in this Annual Report.

New initiatives in which INPA plays an important role are the R&D for the next generation of high energy neutrino detector and the development of a Nuclear Astrophysics Data Center. This list is likely to include KamLAND and CUORE in the near future.

INPA hosted or co-hosted the following meetings and / or workshops:

March 9, 1998: Meeting to develop a proposal for a small telescope to be placed on the Space Station.

June 26-27, 1998: Meeting to develop a proposal for the "Deep Ice Science and Technology Center," to be submitted to the National Science Foundation (co-hosted by the UC Berkeley Physics Department).

August 13-14, 1998: Meeting to define future directions for research within the Institute of Nuclear and Particle Astrophysics

October 28-30, 1998: Workshop on Digital Optical Module system in advance of AMANDA collaboration meeting

February 20-22, 1999: Site visit by an NSF committee reviewing the UC/LBNL proposal for a "Deep Ice Science and Technology Center" (co-hosted by the UC Berkeley Physics Department).

April 7-11, 1999: Meeting of AMANDA collaboration.

Visitors are invited to spend time from a week to several months at the Institute. This year's visitors included: Michael Shane Burns – 5/19-7/3; Munther Hindi – 9/1-12/31; Guenter Sigl – 10/1-10/4; Maurice Goldhaber - 11/10-11/17; Daniel DiGregorio - 12/3-12/22.

Additional information on the Institute and its activities can be found on the World Wide Web under the URL http://www-inpa.lbl.gov/.